

OCCURRENCE OF LARVAL *ILLEX ILLECEBROSUS* AND OTHER YOUNG CEPHALOPODS IN THE SLOPE WATER/GULF STREAM INTERFACE

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Abstract.—Specimens and data suggest that larval short-finned squid, *Illex illecebrosus*, may concentrate in water where density (σ_t) is approximately 26.7, indicating that spawning occurs in the subsurface interface where Slope Water mixes with the Gulf Stream. Because these water masses occur year-round within the range of *I. illecebrosus*, spawning may be a prolonged or progressive process along the shoreward edge of the Gulf Stream. The distribution of other species indicates mesoscale spatial separation of young cephalopods in the vicinity of the Gulf Stream.

Among many unanswered questions in cephalopod ecology, two currently are receiving much attention: (1) what are the season and site(s) of spawning for the commercially important species *Illex illecebrosus* and (2) what factors in the early life history of the species are crucial to its survival and recruitment to the fishery?

A multinational effort was organized by Canada, Japan, and the United States to attempt to answer these questions. Intensive directed sampling for the early stages of *I. illecebrosus* was conducted during February and March 1982 on cruise 8201 of the Japanese Research Vessel *Kaiyo-Maru*. Personnel from all three sponsoring nations participated in the two-part cruise.

The area sampled was centered on the Gulf Stream east of New England and south of Nova Scotia. During the second leg of the cruise, from which our specimens were obtained, the Gulf Stream was meandering through the sampling area. Thus, the 40 stations for which we have data include water masses characteristic of Boreal Slope Water, the Gulf Stream, and the Sargasso Sea.

Materials and Methods

Sampling was done primarily with oblique tows. A model 1271 open bongo-net system

with 61 cm diameter mouth opening and 0.5 mm mesh was used to sample between the surface and 200 m depth. Sampling between the surface and 1000 m depth was done with an open midwater trawl (KMT; 100 m long, 18 mm mesh cod-end), and a rectangular midwater trawl (KYMT; 3 × 3 m mouth opening, 17 m long, 1.7 mm mesh cod-end). Data on hydrographic conditions were collected using expendable bathythermographs and multiple bottle casts for conductivity, temperature, and dissolved oxygen.

The biological samples were sorted at sea and field identifications were attempted for larval and juvenile *Illex*, sometimes under rather severe weather conditions. Preserved specimens then were divided among the representatives of the participating countries: 50% to the Japanese, 25% to the Canadian, and 25% to the U.S. participants.

Results

The material available for analysis consisted of 66 specimens that were identified to 18 taxa. Young *Illex* (we believe *I. illecebrosus*; see Vecchione 1979) was the most abundant cephalopod collected (Table 1). The material also included several other taxa for which our current knowledge of early

Table 1.—Ranking by abundance of cephalopod specimens from Leg II of *Kaiyo-Maru* cruise 8201.*

Taxon	No. of specimens	Rank	Mantle length (mm)		
			Min.	Median	Max.
<i>Illex</i> sp. (cf. <i>illecebrosus</i>)	16	1	3.0	4.0	10.7
Octopodidae	6	3	3.7	4.0	6.1
<i>Gonatus fabricii</i>	6	3	2.7	7.0	13.3
<i>Ommastrephes</i> sp.	6	3	2.1	3.8	8.1
<i>Leachia</i> sp.	4	5.5	14.7	17.9	28.0
<i>Pterygioteuthis</i> sp.	4	5.5	3.1	4.6	10.0
<i>Abralia</i> sp.	3	8	2.8	4.3	4.7
<i>Octopoteuthis</i> sp.	3	8	3.1	6.3	6.8
<i>Teuthowenia megalops</i>	3	8	4.3	5.0	5.7
<i>Pyroteuthis margaritifera</i>	2	12.5	2.7	3.3	3.9
<i>Onychoteuthis banksii</i>	2	12.5	3.8	4.8	5.8
<i>Onykia caribaea</i>	2	12.5	6.7	7.0	7.3
<i>Ctenopteryx sicula</i>	2	12.5	2.8	3.0	3.1
<i>Brachioteuthis</i> sp.	2	12.5	2.1	2.5	2.8
unid. oegopsid	2	12.5	2.3	2.7	3.1
<i>Abraliopsis</i> sp.	1	16	8.2	8.2	8.2
<i>Histioteuthis</i> sp.	1	16	2.7	2.7	2.7
<i>Ornithoteuthis antillarum</i> (?)	1	16	2.6	2.6	2.6
Total	66 specimens	18 taxa			

* Represents 25% of total collected; see text.

life history is even more limited. These taxa include young *Gonatus fabricii*, as well as several other ommastrephids, onychoteuthids, enoploteuthids, cranchiids, and octopodids.

Station locations and isotherms at the surface and at 200 m depth are shown in Fig. 1. These depths were selected because they represent the sampling envelope of the oblique bongo tows. The temperature structure shows the turbulent nature of the current in the sampling area, as is typical of the transition zone between the Gulf Stream and the North Atlantic Drift. It also shows the substantial variability in thermal structure within the sampled depth range. Distribution of the five most abundant taxa is shown also in Fig. 1. Based on this limited subset of the complete set of data, we see indications of mesoscale spatial segregation among these taxa. Whereas *Gonatus fabricii* was collected only along the Slope-Water edge of the system, *Illex illecebrosus* and the unidentified octopods were concentrated along the central axis of the system, and *Leachia*

sp. and *Ommastrephes* sp. appeared to be concentrated on the Sargasso Sea side of the system.

The six stations at which *Illex* were collected included a broad range of surface temperatures (Fig. 2A). Inferences on the distribution of young *Illex* based only on surface conditions where oblique tows collected specimens would indicate eurytopic habitat requirements, from 8°C to nearly 20°C. However, based on our earlier work with sampling programs from shelf and slope waters of the western North Atlantic (Roper and Lu 1979, Vecchione 1979), we have reason to believe that larval *I. illecebrosus* are concentrated deeper in the water column. At approximately 100 m depth all of the temperature sections begin to converge and by 150 m the temperatures concentrate around 13°–18°C. If we assume, based on earlier studies, that this is close to the depth at which most of the *Illex* were collected, then we have reason to point out strong similarities among all of these stations.

The temperatures and salinities of these

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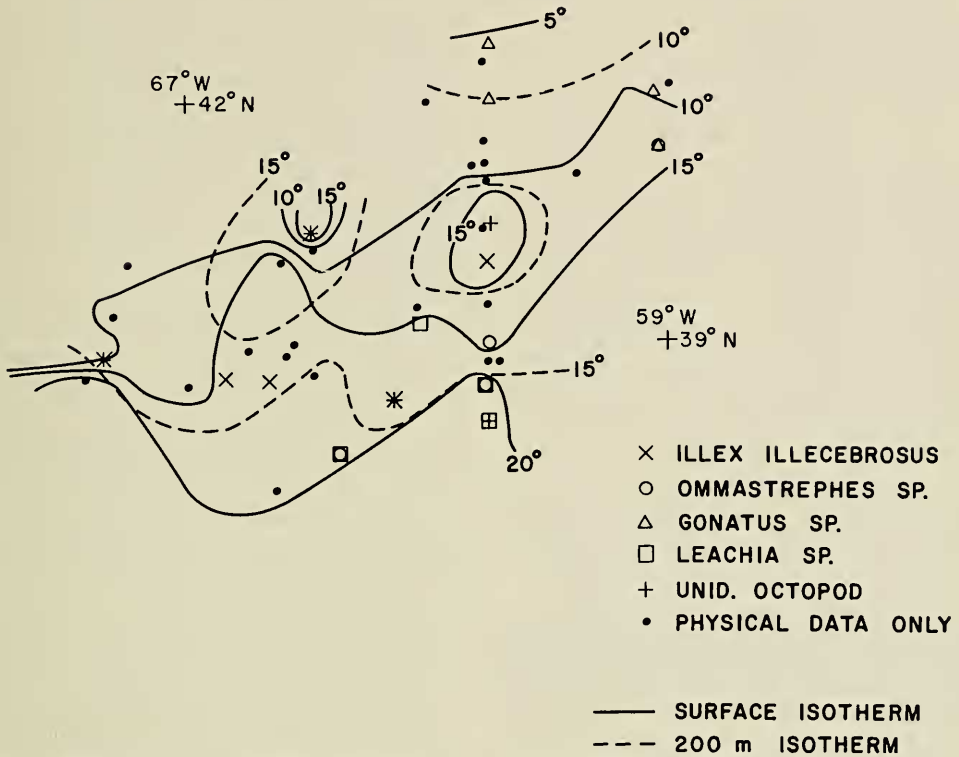


Fig. 1. Study area showing station locations, surface and 200 m isotherms, and occurrence of the five most abundant cephalopod taxa (Kaiyo-Marukruise 8201, Feb-Mar 1982).

stations at 150 and 200 m depths are shown in Fig. 2B. These waters are approximately isopycnal at σ_t of about 26.7, an indication of subsurface mixing. The isopycnal mixing extends between what Wright and Parker (1976) refer to as the "slope-water thermostat" and the Gulf Stream. Some captures are in the discrete water types and some are in the intermediate water; the aggregate of the captures is what would be expected in subsurface mixing between two water types because it extends along isopycnal lines. Based on these indications, we believe that hatching probably occurs in subsurface waters at the interface between the Slope Water and the Gulf Stream. Since both of these water masses occur within the distri-

butional range of *I. illecebrosus* throughout the year, these data may also indicate a prolonged spawning season along the shoreward edge of the Gulf Stream over a very extensive latitudinal range.

Discussion and Recommendations

Prior to O'Dor and Durward's (1979) demonstration that *Illex illecebrosus* spawns pelagic egg masses, it was assumed that *Illex* probably spawned demersally on the continental slope (Roper and Lu 1979, Vecchione 1979). The concept that an obligate relationship exists between the Gulf Stream and the early life history of *Illex* is now gaining support (Coelho 1985, O'Dor and

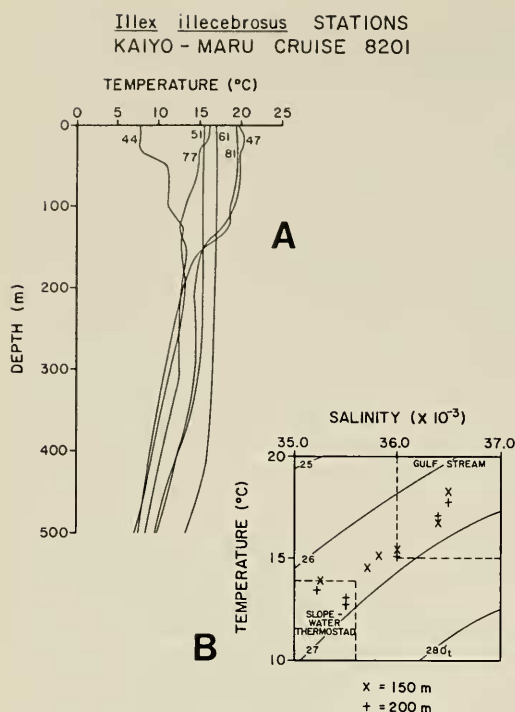


Fig. 2. A, Temperature profiles at Kaiyo-Maru stations where *Illex illecebrosus* larvae were captured (station numbers indicated); B, T-S diagram of Kaiyo-Maru stations where *Illex illecebrosus* larvae were captured with notation of water-mass type (cruise 8201, Feb-Mar 1982).

Balch 1985, Rowell et al. 1985, Hatanaka et al. 1985). Additionally, our data from this cruise and unpublished observations from other cruises (Vecchione et al. 1986) indicate that similar relationships may exist for other cephalopod species.

Hypotheses are now being proposed to explain this relationship for *I. illecebrosus*, but conclusive tests of these hypotheses are very difficult because of problems with sampling and taxonomy. Not only has it so far been impossible to collect *Illex* eggs in the field (O'Dor and Balch 1985) and difficult to collect planktonic young, but specific identification of the young must be inferred from adult distributions. South of Cape Hatteras such identifications are confounded by the presence of a complex of three species (*I. illecebrosus*, *I. coindetii*, and *I.*

oxygonius) which even as adults are very similar morphologically. Thus, distributional patterns of larvae collected on cruises in or near the area of species overlap (e.g., Rowell et al. 1985) may result from spawning by one or more of these species.

Often, inferences on larval ecology have been based on surface conditions at stations where the larvae have been collected in oblique subsurface tows. This practice is particularly faulty for a species like *Illex illecebrosus* for which data on vertical distribution are extremely limited. For instance, assumptions like that of Rowell et al. (1985) that "it is likely that the majority [of *Illex* larvae] were taken in the upper 50 m" of oblique tows between the surface and 200–300 m depth are not supported by data. Observations on *I. illecebrosus* egg masses by O'Dor and Balch (1985) indicate that the egg masses in nature are probably suspended in midwater at about the depth of the pycnocline (about 150 m in our samples). Furthermore, O'Dor et al. (1986) have shown that laboratory-hatched *I. illecebrosus* larvae avoid the surface but are capable of diel vertical migration from mesopelagic depths. This is consistent with the very limited observations by Hatanaka et al. (1985) of a diel shift in the depth of maximum abundance of larval *Illex*.

An analysis of the distribution of *Illex illecebrosus* collected off Nova Scotia during Kaiyo-Maru cruise 8201 has been compiled by Hatanaka et al. (1985). This report presumably was based on field-log entries of identifications for all specimens, since several specimens remained in our possession as a result of subdividing the catch upon completion of the cruise. During the first leg of the cruise, discrete-depth bongo tows were attempted at four stations. These attempts were successful at only one station in collecting a complete set of samples (from several depth strata between the surface and 200 m depth). Subsequently, discrete-depth sampling was abandoned. Inferences by Hatanaka et al. (1985) on *Illex* larval distri-

bution were therefore based on physical conditions in the 0–100 m depth range at oblique-tow stations (however, their very limited discrete-depth data indicated that larval *Illex* may be concentrated at 100 m or greater depth during the daytime). Inferences by Hatanaka et al. (1985) about the relationship between *Illex* larval distribution and the boundary between the Gulf Stream and Slope Water do not contradict our impressions which are based on reexamination of a subset of the collections, but we do feel, however, that some deficiencies in the data must be pointed out so that similar problems can be avoided in the future.

Although we are able to speculate about the larval occurrence and distribution of *I. illecebrosus* and other species, a more precisely defined sampling program probably would have provided sufficient data to test our hypothesis. To achieve this, we recommend several changes in future sampling programs. First, once the general area and season of larval abundance have been determined for the target species, discrete-depth sampling should be considered a requirement for the study of early life history. Such a sampling regime can be accomplished either with bongo systems or with multiple opening/closing systems such as the MOCNESS Multiple Opening-Closing Net and Environmental Sensing System (Weibe et al. 1976). If time and funding constraints are imposed on the number of samples that can be collected and processed, then the number of stations occupied should be reduced to ensure that discrete-depth sampling can be accomplished. Second, definitive sorting and verification of species-level identifications should not be attempted at sea. Our cross-checks of the field logs against subsequent laboratory identifications indicate that several of the field identifications were incorrect. Even under the best of conditions use of a microscope at sea is difficult. Hatchlings of only about 2 mm or less in length are easily overlooked sloshing about in a petri dish of plankton; furthermore, the

minute taxonomic characters required for identification are difficult to distinguish, let alone confirm. Thus, we cannot be confident enough in the shared, complete set of field-log entries of identifications to infer distribution and abundance based on all specimens collected but subdivided prior to verification of identifications.

A complete set of samples from this cruise, examined by a specialist in cephalopod systematics, would have been of considerable value in fulfilling the goals of this study. An additional benefit of onshore examination of all specimens by a single specialist is that the distribution of non-target species, such as *Gonatus fabricii*, could confidently be assessed along with the distribution of larval *Illex*.

We very strongly support international collaborative studies and coauthorship as an effective, efficient means of helping to answer many of the important questions we face in biological oceanography, fisheries biology, and systematics. To help achieve these ends, we recommend that future collections be identified and analyzed at one institution, prior to dividing the material among participating organizations. This will ensure consistency of analysis and interpretation without diminishing the collaborative effort.

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Literature Cited

- Coelho, M. L. 1985. Review of the influence of oceanographic factors on cephalopod distribution and life cycles.—Northwest Atlantic Fisheries Organization Scientific Council Studies 9:47–57.
- Hatanaka, H., A. T. Lange, and T. Amaratunga. 1985. Geographical and vertical distribution of short-finned squid (*Illex illecebrosus*) larvae in the northwest Atlantic.—Northwest Atlantic Fisheries Organization Scientific Council Studies 9: 93–99.
- O'Dor, R. K., and N. Balch. 1985. Properties of *Illex illecebrosus* egg masses potentially influencing larval oceanographic distribution.—Northwest Atlantic Fisheries Organization Scientific Council Studies 9:69–76.
- , and R. D. Durward. 1979. A preliminary note on *Illex illecebrosus* larvae hatched from eggs spawned in captivity.—Proceedings of the Biological Society of Washington 91(4):1076–1078.
- , E. A. Foy, P. L. Helm, and N. Balch. 1986. Locomotion and energetics of hatchling squid, *Illex illecebrosus*.—American Malacological Bulletin 4:55–60.
- Rowell, T. W., R. W. Trites, and E. G. Dawe. 1985. Distribution of short-finned squid (*Illex illecebrosus*) larvae and juveniles in relation to the Gulf Stream frontal zone between Florida and Cape Hatteras.—Northwest Atlantic Fisheries Organization Scientific Council Studies 9:77–92.
- Roper, C. F. E., and C. C. Lu. 1979. Rhynchoteuthion larvae of ommastrephid squids of the western North Atlantic, with the first description of larvae and juveniles of *Illex illecebrosus*.—Proceedings of the Biological Society of Washington 91(4):1039–1059.
- Vecchione, M. 1979. Larval development of *Illex Steenstrup*, 1880 in the northwestern Atlantic with comments on *Illex* larval distribution.—Proceedings of the Biological Society of Washington 91(4):1060–1075.
- , C. F. E. Roper, C. C. Lu, and M. J. Sweeney. 1986. Distribution and relative abundance of planktonic cephalopods in the western North Atlantic.—American Malacological Bulletin 4: 101.
- Weibe, P. H., K. H. Burt, S. H. Boyd, and A. W. Morton. 1976. A multiple opening/closing net and environmental sensing system for sampling zooplankton.—Journal of Marine Research 34: 313–326.
- Wright, W. R., and C. F. Parker. 1976. A volumetric temperature/salinity census for the Middle Atlantic Bight.—Limnology and Oceanography 21(4):563–571.

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